lying propositions, so interesting, so illuminating, often so amazing.

Finally, but far from exhausting the list, it remains to mention the great subjects of invariants and groups. Both of them admit of definition perfectly intelligible to disciplined laymen; both admit of endless elementary illustration, of having their mutual relations simply exemplified, of being shown in historic perspective, and of being strikingly connected, especially the notion of invariance, with the dominant enterprise of man: his ceaseless quest for the changeless amid the turmoil and transformation of the cosmic flux.

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PRELIMINARY REPORT ON A SHALER MEMORIAL STUDY OF CORAL REEFS

A LIBERAL grant from the Shaler Memorial Fund of Harvard University, supplemented by a generous subsidy from the British Association for the Advancement of Science with an invitation to attend its meeting in Australia last August as a foreign guest, enabled me to spend the greater part of the year 1914 in visiting a number of islands in the Pacific Ocean with the object of testing various theories that have been invented to account for coral reefs. Thirty-five islands, namely, Oahu in Hawaii, eighteen of the Fiji group, New Caledonia of which the entire coast line was traced, the three Loyalty islands, five of the New Hebrides, Rarotonga in the Cook group, and six of the Society islands, as well as a long stretch of the Queensland coast inside of the Great Barrier reef of northeastern Australia, were examined in greater or less detail. A brief statement of my results has been published in the *Proceedings of the National Academy of Sciences* for March, 1915. A full report will appear later, probably in the *Bulletin of the Museum of Comparative Zoology* at Harvard College. The general conclusions reached are here briefly summarized.

Any one of the eight or nine theories of coral reefs will satisfactorily account for the visible features of sea-level reefs themselves, provided the postulated conditions and processes of the invisible past are accepted: hence a study of the visible features of the reefs alone can not lead to any valid conclusion. Some independent witnesses must be interrogated, in the hope of detecting the true theory. The only witnesses, apart from sections obtained by deep and expensive borings, available for sea-level reefs are the central islands within oceanic barrier reefs, or the mainland coast within a continental barrier reef. The testimony of these witnesses has been too largely neglected, apparently because most investigators of coral reefs have been zoologists, little trained in the physiography of shore lines. Elevated reefs afford additional testimony in their structure and in the relation of their mass to its foundation; but these witnesses also have been insufficiently considered, perhaps because most investigators of reefs have, as zoologists, been little trained in structural geology; hence it seemed desirable to give as much time as possible on the Pacific islands to questioning the independent witnesses above designated, rather than to the study of the reef themselves.

The testimony of the first group of witnesses —the central islands of barrier reefs—convinced me that Darwin's theory of subsidence is the only theory competent to explain not only the development of barrier reefs from fringing reefs, but also the shore-line features of the central (volcanic) islands within such reefs; for the embayment of the central islands testify emphatically to subsidence, as Dana long ago pointed out: thus my results in the study of this old problem of the Pacific agree with those of several other recent students, especially Andrews, Hedley and Taylor of Australia, and Marshall of New Zealand. Darwin's theory of subsidence also gives by far the most probable explanation of atolls; for it is unreasonable to suppose that a subsidence of the ocean bottom should occur only in regions where the central islands of barrier reefs are present to attest it, and not in neighboring regions where reefs of identical appearance,

but without a central island, are given another name.

The testimony of the second group of witnesses—massive elevated reefs such as occur on certain Fiji Islands—convinced me that Darwin's theory of subsidence gives the only satisfactory explanation of the origin of such reefs also; for their limestones rest unconformably on the normally eroded surface of a preexistent foundation. The erosion of the foundation surface shows that it stood above sea-level before the reef was deposited upon it; and the occurrence of the reef shows that the eroded foundation subsided to receive its marine cover. Only after this subsidence was the compound mass uplifted. The mere occurrence of elevated reefs above sea level does not for a moment prove that they were formed during the emergence of their foundation.

All the still-stand theories of barrier reefs—that is, all the theories which involve a fixed relation of the reef foundation to the sea level during the formation of the reef mass—are excluded by evidence of submergence found in the embayed shore lines of the central islands within barrier reefs. It may seem overbold thus at a stroke to set aside several well-known theories, accepted by experienced observers; and so indeed it would be if these observers had discussed the features of the embayed central islands and had explicitly shown that their embayments are not due to submergence, but to some other cause. It is, however, a regrettable fact that the observers who adopted one or another of the still-stand theories took, like Darwin himself, practically no account of the embayed central islands, essential as the testimony of these islands is in the solution of the coral-reef problem. Such neglect is all the more remarkable in view of the clear statement, long ago published by Dana, regarding the pertinence and the value of the testimony afforded by the central islands of barrier reefs.

The glacial-control theory of coral reefs, recently elaborated by Daly with special reference to the lagoons of atolls, will not hold for barrier reefs. This theory assumes that no subsidence of the reef foundations took place, and explains the lagoon floors of atolls as platforms abraded across preglacial sea-level reef-masses by the lowered and chilled sea of the glacial period after the corals were killed; the preglacial reef-masses having been formed by upward or outward growth on their still-standing foundations. It then explains the encircling reefs which now surround the lagoons as having been built up while the sea was rising and warming in postglacial time. But if the broad lagoons of large atolls, 20 or 30 miles in diameter, were thus formed, the central islands within narrow-lagoon barrier reefs should be cliffed all around their shore line, and they are not. Furthermore, this theory explains the embayments of central islands within barrier reefs as occupying new-cut valleys that were eroded during the glacial period of lowered sea level; but if this were the case, the new-cut valleys should be prolonged upstream from the embayment heads as incisions in the floors of preglacial valleys, thus producing a "valley-in-valley" landscape; and this is not true in any one of the hundreds of embayments seen during the past year. Furthermore, many of the embayments are so wide that, if they were opened by slow subaerial processes, all the spur ends ought to have been well cliffed by the sea; yet, as above stated, they are not cliffed. Finally many of the embayments are too wide to have been eroded during the last glacial epoch, or even during all the glacial epochs of the entire glacial period, if the valleys of the formerly glaciated volcanoes of central France are taken as standards of the amount of erosion that could be accomplished in such masses during such intervals of time. The glacial-control theory thus proves incompetent to explain barrier reefs, and it is therefore held to be generally incompetent to explain atolls also; it may have more importance on the borders of the coral zone, where the corals would most likely have been killed during the glacial period: the Marquesas Islands promise interesting results in this connection. The glacial-control theory has its greatest importance in conjunction with Darwin's theory of subsidence, for submergence during subsidence may have been

almost neutralized by the lowering of the sea-level during the oncoming of a glacial epoch, and at such a time coral reefs would broaden and lagoons would become shallow; but with the passing of a glacial epoch the return of ice-sheet water to the ocean would accelerate the submergence due to subsidence, and at such a time coral reefs might be more or less completely drowned: thus the discontinuity of certain reefs on so-called "platforms" may be explained.

All the phenomena which testify to the formation of coral reefs on subsiding foundations can be equally well explained by the assumption of a rise of the ocean surface around or over fixed foundations: but a rise of the ocean surface in any coral-reef region demands a rise of the whole ocean surface; and if the coral-reef foundations are to stand still, a rise of the whole ocean surface can be explained only as the diminished result of a greater rise of the ocean floor in some non-coral-reef region. The conditions involved in this alternative for the simple theory of local subsidence are so extravagantly improbable that, as soon as they are explicitly defined, they must be rejected.

No absolute demonstration of the origin of coral reefs, or, for that matter, of any other geological structure, is possible: the most that can be hoped for is a highly probable conclusion. The conclusions announced above in favor of Darwin's theory are believed to have about the same order of probability as that usually accepted as "proof" in geological discussions.

A number of local conclusions may be briefly announced as follows:

The elevated reef along the south coast of Oahu, Hawaii, was formed during or after a sub-recent period of subsidence, for its limestones enter well-defined valleys that must have been eroded when the island stood higher than now, before the reef-limestones were deposited in them.

The Fiji group has suffered various movements of subsidence and elevation by which its many islands were affected in unlike ways. Elevation has taken place at different times in different islands, for some of the elevated reefs are elaborately dissected, others are very little dissected, and still others remain at sea-level. The embayments due to the latest subsidence on the larger islands, Viti Levu and Vanua Levu, are now largely filled with delta plains. All the reefs, those now elevated as well as those at sea-level, appear to have been formed during periods of subsidence, the evidence afforded by the elevated reefs of Vanua Mbalavu, Mango and Thithia, being especially significant on this point. The medium-sized island of Taviuni has few visible reefs, because its flanks and shores are flooded by sheets of recent lava. The small island of Wakaya seems to be a tilted block of lava beds, not a dissected volcano.

The extensive barrier reef of New Caledonia has grown up during a recent subsidence by which that long and maturely dissected island has been much reduced in size and elaborately embayed; but unlike most encircled islands this one was strongly cliffed around its southeastern end and along much of its northeastern side before the recent subsidence took place.

The two southeastern members of the Loyalty group, Maré and Lifu, are former atolls, evenly unlifted about 300 feet: Maré shows a small hill of volcanic rock in the center of its limestone plateau or elevated lagoon floor. Uvea, the northwestern of the three Loyalty Islands, is a slightly tilted atoll; its eastern side shows an uplifted reef in crescentic form, 100 or more feet high at the middle of its crescent, and slowly descending to sea-level at its horns; the tilted lagoon floor slowly deepens westward and is enclosed by disconnected, upbuilt reef-islands.

The New Hebrides show signs of uplift in their elevated reefs, and of depression in their embayments. There is some evidence that certain uplifted fringing reefs on the island of Efaté, near the center of the group, were formed during pauses in a subsidence that preceded their uplift, and not during pauses in their uplift as inferred by Mawson. The narrowness of the lagoons enclosed by the barrier reefs that encircle certain strongly embayed islands in this group may be explained by supposing alternations of slow and rapid subsi-

dence, so that the earlier-formed reefs, which began to grow when the subsidence was slowly initiated, were drowned when it was later accelerated; and new reefs, thereupon begun on the shore line of that time would after a second period of slow subsidence stand near the present shore line, though the shore line is strongly embayed because the total subsidence has been large. The absence of reefs around the island of Ambrym is due to its abundant eruptions in recent time, the latest one being in December, 1913; scattered corals were seen growing on one of its sea-cliffed lava-streams, thus illustrating the initial stage of a fringing reef.

The Great Barrier reef of Australia, the largest reef in the world, with a length of some 1,200 miles and a lagoon from 15 to 70 or more miles wide, has grown upward during the recent subsidence by which the Queensland coast has, after a long period of still-stand, been elaborately embayed, as was pointed out by Andrews in 1902. A very recent uplift of ten feet has occurred, as was long ago noted by Jukes. There is reason for believing that a broadened reef-plain, with extensive land-fed deltas along the continental margin, had been formed before the recent subsidence took place; and it is this broadened reef, now submerged, that is thought to form the "platform" on which the Great Barrier reef has grown up. Guppy's suggestion that the platform or "submarine ledge" is due to marine abrasion before coral reefs were established here and that no subsidence has taken place can not be accepted. It is highly probable that the well-attested recent subsidence was due to a gentle flexure, by which the off-shore sea-bottom was bent down; and if so, the coastal submergence will give much too small a measure of the thickness of the distant barrier reef. In this respect the Great Barrier reef along the shore of a continent differs significantly from smaller barrier reefs around oceanic islands, in which the subsidence of the island and its reef are essentially uniform.

A few hours on shore at Raretonga, the southernmost member of the Cook group, sufficed to show that extensive embayments formerly entering its elaborately carved mass are now occupied by delta plains and perhaps in part by slightly elevated reef- and lagoon-limestone.

Five islands of the Society group exhibit signs of recent subsidence in their intricately embayed shore lines, as has lately been announced by Marshall. A sixth, the cliff-rimmed island of Tahiti, the largest and youngest of the group, has suffered moderate subsidence after its cliffs were cut, but the resulting bays are now nearly all filled with delta plains which often advance into the narrow lagoon; hence a pause or still-stand has followed the latest subsidence. All the barrier reefs of this group appear to have been formed during the recent subsidence that embayed their central islands.

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Scientific Notes and News

Dr. Richard P. Strong, professor of tropical diseases at the Harvard Medical School, has been appointed leader of the American Red Cross Sanitary Commission, which will assemble in Salonica about the middle of next month and proceed to the districts of Servia and Austro-Hungary which are stricken with epidemics of typhus, cholera and other contagious diseases. The commission will be supported by the Red Cross and the Rockefeller Foundation. Dr. Strong has already sailed for Greece, and the rest of the expedition will sail by the end of this month. It includes Dr. Thomas W. Jackson, of Philadelphia; Dr. Hans Zinsser, professor of bacteriology, Columbia University; Dr. Andrew W. Sellards, Dr. George C. Shattuck and Dr. Francis B. Grinnell, of the Harvard Medical School. Dr. Nicolle, the French expert on typhus, has been invited to cooperate with the commission. Mr. Charles S. Eby, of Washington, lately connected with the United States Immigration service, is disbursing officer and secretary for the commission.

The Rockefeller Foundation has made comprehensive plans for improving medical and hospital conditions in China. These are based